volume 3 · number 2 · spring 1989

agricultural history

a publication of the agricultural history society edited at the agricultural history center university of california, davis

special symposium issue on
Climate, Agriculture, and History
Edited by **David C. Smith**
University of Maine—Orono

Contents

Wheat Production and/or Productivity As Climatic Proxy Data: Bologna, 1815–1860

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Bologna, Italy, has one of the longest time series of data on climate available to modern scientists.[1] Recently a group of historians and physicists have begun to explore them, thanks partly to funding from the Department of Culture of the Regional Council of the Emilia-Romagna, and to joint support from the EEC and the Department of Agriculture of the Regional Council. Research has been developed along three main lines: (1) an inquiry into the reasons that Bologna scientists took such an early interest in climate; (2) the study of climate itself and its relationship to the broader issues involved in its physical analysis; and (3) the analysis of the relationship between climate and agriculture in the period covered by the series.[2]

In analyzing the climate "experienced" by the peasants of Bologna we have followed two main routes—first, the influence of climate not only on agricultural work but also on the social relationships of production and second, as accurate an evaluation as possible of the "pure" influence of climate on the agricultural yield.[3] By pure climatic influence we mean the

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1. This work can be considered as an addition to H.H. Lamb, *Climate, Present, Past and Future. II. Climate History and the Future,* (London, 1977, 22–5). With regard to this issue see E. Baiada, S. Comani, R. Finzi, D. Salmelli, *Sul clima di Bologna e dello spazio emiliano-romagnolo nel secolo XVIII: fonti e obiettivi di una ricerca in corso,* "Passato e presente," 2/82, p. 218.

2. All these strands of research can be found in R. Finzi, a cura di, *Le Meteore e il frumento, Clima agricoltura meteorologia a Bologna nel 700,* (Bologna, 1986).

3. On the first issue see R. Finzi, "Vanga e clima a Bologna 1814–1858," in *Studi in memoria di Luigi Dal Pane,* (Bologna, 1982), 685–710. R. Finzi, S. Comani, "Metayers, Bêche et Climat: La Plaine de Bologne, 1718–1744," in *Revue d'histoire moderne et contemporaine,* XXXI, 472–488. On the second issue see R. Finzi, "Il Sole, la pioggia, il pane e il lavoro. Note su

agricultural history volume 62 · number 3 · Spring 1989. © agricultural history society

effects of climate (or of some of its elements) on the growth of plants and their fruits without taking into account the "indirect" effects of the course of weather on harvests. Such indirect effects are, for example, the proliferation of field pests under certain climatic conditions often described in agricultural sources.

Our work in this area has made us aware of the climate's direct influence on agricultural yield and we have become more aware of the need to obtain broader and more accurate information on the climate and its historical role in the formation of human societies.

During our research we have obtained probable estimates of climatic data from the productivity or production data on a particular crop, which, in this case, is wheat. Harvests have always been a good source for a climatic profile.[4] Yet, the analysis of the relationship has led to more hypothetical inferences than to solid conclusions. If our method survives further checks and replication analyses, we will get much more refined, albeit partial, information for a long period before the use of instruments. Our first estimates suggest positive results.

The choice of wheat as a test crop was compelling: It is the staple product of European agriculture, both in reality and in the common imagination. As far as our research is concerned, it also had other advantages, since given that it has been thoroughly studied for the production of bread, its characteristics and requirements are well known. In particular we have access to a wide knowledge of its needs in terms of water supply and of the thermal reactions during the growth period. A series of empirical but reliable tests led us, in addition, to the conclusion that the most widely used variety of wheat in our area, between the eighteenth and the twentieth centuries (that is, the period during which our research is focused), belongs to the *triticum aestivum* (Hexploid n=21) which is quite similar in its phenological phases to the varieties still in use today.[5] It was thus possible, in the analysis of crops over the past centuries, to rely on a methodology which has been developed for contemporary agriculture.

We begin with a brief description of the data at our disposal. We have climate surveys dating back to 1716, with some missing intervals between 1774 and 1814. The methods used in these surveys has since evolved, but

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clim, raccolto, calendario agrario nel Bolognese durante il secolo XVIII," in *Le Meteore et il frumento* . . . . 354–369; R. Finzi, (research director) with the collaboration of E. Baiada, M. Bonzagni, G. Lo Vecchio, F. Di Palma, "Andamento Climatico e suo rapporto con la produttivita agricola: Bologna 1815–1960, Relazione finale," submitted to EEC under contract No. CLI□097.I. Paper is available from the Istituto per la storia di Bolgona, Via dé Musei 6, 40124, Bologna, Italy.

4. The most recent example of this is C. Pfister, "Fluctuations climatiquies et prix cerealiers en Europe du XVI au XX siecle," *Annales* XLIII, np. 1, 25–53.

5. See Finzi, "Il Sole, la pioggia . . ." 358–59.

the center of study has always remained in the head office of the Academy of Science, which later became the head office of the University of Bologna. The instruments used in the survey have, however, had their location changed slightly within the premises. This change is not an irrelevant factor in the terms of the data's reliability.[6] The work of a member of our team, Enrica Baiada, has helped solve problems created by this shift, which has resulted in greater accuracy.

The observation center is placed within the city walls, though this area was considered a peripheral one in the eighteenth and nineteenth centuries. We were faced with two technical problems: (1) it was possible that the data was influenced by the microclimate of the town, and (2) we were not sure that a survey carried on for only one section of the area could be valid for the entire territory of Bologna.

To deal with these problems we formed the following hypotheses:

(a) Until the first half of the nineteenth century the town microclimate had no influence on our data, we assumed it was reliable from this point of view; and

(b) the data could also represent the plain around Bologna, although we would face a different case with the hills or the mountains of the surrounding territory.

We checked these two hypotheses from several angles. The results give us clear evidence that we possess carefully screened and reliable data for the whole area of the Bologna plain.[7]

Much data are available on harvests. For the eighteenth century, we have a synthetic indicator in the tables which lists the influx of wheat to the city from the second half of the sixteenth century until the arrival of Napoleon, with an appendix covering the period of the restoration. The chief town of the province had to be supplied by all its countryside, with the exception of such areas as mountain regions, which had a very low level of production. Wheat and other cereals or legumes came mostly from the plain. Authorities had, among other matters, to assess this influx. The tables referring to grain consignment have different levels of reliability, depending on what we aim to discover. For example, they seem to be of no use if we want to estimate total annual wheat production.[8] We thought, nevertheless, that the swings in records must be partially related

6. E. Baiada, "Da Beccari a Ranuzzi: La meteorologia nel Accademia Bolognoese nel secolo XVIII" in *Le Meteore e il frumento*. . . 178–183.

7. Finzi, "Il sole, la pioggia. . . ." 351–353. Baiada, Comani, Finzi, Salmelli, graf 1, p. 228. R. Finzi, E. Baiada, "L'Afirmazione del mais nelle campagne Bolognesi: un mutamento del regime alimentare" in *Popolazione ed economia dei territori Bolognesi durante il Settecento* (Bologna, 1985), 294–302.

8. R. Zangheri, (1959) now included in R. Zangheri, *Agricoltura e contandini nella storia d'Italia* (Turin, 1977), 148–9.

to harvest fluctuations. As the eighteenth century was, for this area, a fairly stable period as far as the political and demographical[9] aspects are concerned, we compared the tables of wheat consignments to Bologna during this period (excluding wheat imported from abroad) with a series of yield ratios. The two outlines emerged as being quite similar, if not completely concordant (Table 1 and Fig.1). The influx of wheat to Bologna had not been recorded with as much accuracy during the Restoration period, and after the Restoration, such data are not available.

There has never been a thorough verification of the reliability of the Pontifical State's statistics (in which Bologna territory was included before Italy's unification) for the nineteenth century. As far as the agricultural statistics of the Kingdom of Italy are concerned, in the first decades following the unification, they appear, in fact, to be rather dubious.[10] A much better source for the nineteenth-century history of wheat production are farm accounts on which we decided to concentrate our attention. We collected data from 17 farm estates, in which a total of 145 "poderi" were included. (The poderi is the typical agricultural unit of production of central Italy, with a peasant family living within its borders.) Our calculations are based on 3,500 records referring to 89 poderi, belonging to 11 "tenute" (estates). The data we used represent 1 percent of the estimated average wheat harvest of the whole Bologna area during the period considered.[11]

Different, noncontemporary yield ratios can be compared if the agricultural system did not change significantly during the time interval. At the existing level of knowledge we can only reasonably assume that up until the Unification of Italy (1860) the socio-economic situation of the country remained more or less unchanged. In particular, it is only toward the end of the 1850s that we can perceive noticeable signs of technological change. To link the climatic data to the agricultural data we first focused on the period 1815–1860, because in these years the climatic series were collected with more modern methods and the agronomic data was also more "refined."

In temperate areas such as the one in which the Bologna plain is located, the water and thermal needs of wheat have greater variance within

9. With regard to this issue see A. Bellettini, *La popolazione di Bologna dal secolo XV all'Unificazione* (Bologne, 1961), tav. 2, p. 48; A. Bellettini, "L'evoluzione demografica dell 'Italia nel quadro europeo del Settecento, Analogie e particolarita" in S.I.DS., *La popolazione Italiana nel Settecento,* (Bologna, 1980), part 1e tavv. 22 e 23, pps. 38–9.

10. B. Federico, "Par una valutazione critica delle statistiche della produzione agricola Italiana dopo L'Unita (1860–1913)," *Societa e Storia,* V (1985), 87–130.

11. *Andamento Climatico . . . Relazione Finale,* para 3.1 e 3.2, pps. 48–61, e appendix 3.

Table 1. A comparison between Outlines of Yield Ratios and/or Productions of Wheat in Saletto and Rubizzano (*a*), Imola (*b*), Bologna (*c*), 1727–1769 (Index Numbers refer to the Period Average)

Year	*a*	*b*	*c*
1727	.85	.78	.89
1728	.81	.73	.64
1729	1.23	1.17	1.15
1730	1.00	1.01	.96
1731	1.00	.80	.96
1732	.81	.94	.70
1733	.95	.77	.89
1734	1.12	1.10	1.02
1735	.50	.78	.32
1736	1.31	1.34	1.22
1737	1.26	1.15	1.22
1738	1.02	.96	.89
1739	.97	.99	.89
1740	1.54	1.19	1.28
1741	1.16	1.03	1.09
1742	.97	1.08	1.02
1743	.90	.96	1.15
1744	1.26	.85	1.02
1745	1.07	.89	1.09
1746	.92	.82	.77
1747	1.09	.85	.96
1748	1.12	1.10	.89
1749	.85	.92	.89
1750	.95	1.08	1 .02
1751	.64	.87	.64
1752	1.54	1.34	1.41
1753	1.28	1.34	1.22
1754	.92	.91	.83
1755	.59	.89	.70
1756	.85	.82	1.34
1757	1.14	1.01	1.09
1758	1.14	1:15	1.09
1759	1.04	1.12	1.09
1760	1.21	1.26	1.22
1761	1.28	1.31	1.41
1762	1 .02	1.22	1.34
1763	.66	.68	.70
1764	.83	1.01	1.09
1765	.81	.66	.70
1766	.50	.77	.57
1767	.90	.99	1.09
1768	.85	1.05	1.09
1769	.92	1.06	1.22

Sources: a) R.Finzi, -E. Baiada, *L'affermazione del mais nelle campagna bolognesi: un mutamento del regime alimentare?* in *Popolazione ed economia dei territori bolognesi durante il Settecento* (Bologna 1985), tab. 3, 309–310; b) C. Rotelli, *Rendimenti e produzione agricola nell'imolese dal XVI al XIX secolo*, "Rivista storica italiana" 80, I, Tav.1, pp. 121–122; c) *Nota del formento, marzadelli e castellate introdotte nella Citta' di Bologna con i nomi de' governatori e cardinali legati Che la Governarono incominciando dall'Anno 1573, fino al presente* (Bologna 1783).

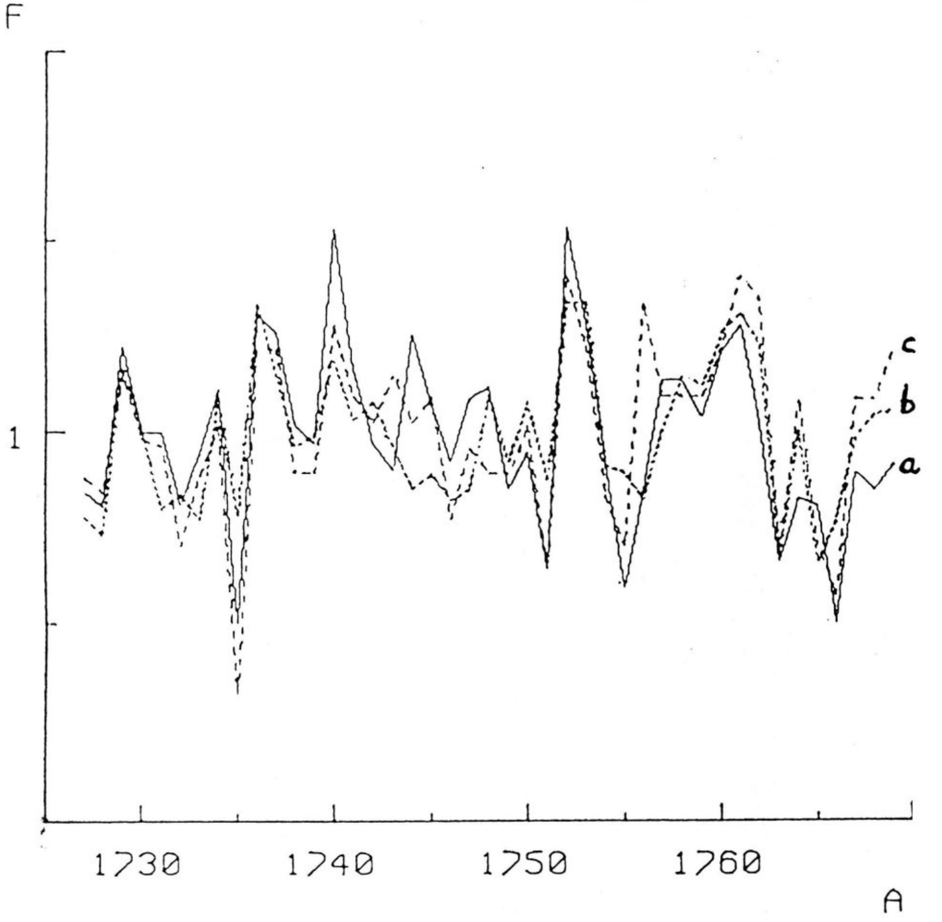

Fig. 1. Comparison of Yield Ratios or Production of Wheat in (a) Saletto, (b) Imola, and (c) Bologna. See Table 1.

the general climate pattern. This means that a "normal" harvest can be achieved under a wide range of climatic conditions. In other words, only during "exceptional" years can the direct influence of the climate on the harvest be established with any certainty. We have thus concentrated our attention on those "exceptional" years.

Low production years may indicate not only climate variability but also may stem from exogenous events which have little or nothing to do with it (such as wars). To pinpoint significant elements that undoubtedly correlate climate to harvest we have chosen those years with high production. A first test of our model was conducted for the high productivity years (≥ 1.2) of the period 1815–1860, that is to say during the following agricultural years (September–June): 1823–24; 1836–37; 1842–43; 1848–49; 1851–52; 1853–54; 1856–57; 1857–58; 1858–59. A second test was conducted for the high productivity years (≥ 1.2) of the period 1716–1774, that is 1718–19; 1719–20; 1720–21; 1722–23; 1724–25; 1739–40; 1751–52; 1755–56; 1760–61; 1761–62.[12]

What have we determined to this point? It is well known that, other things being equal, when all the needs of the different phenological phases are taken into account, the factors that can limit the productivity of a crop, including wheat, are in order of importance: solar radiation, water availability, temperature. Furthermore, we know that in the area under consideration solar radiation is not an inhibiting factor. Additionally, our empirical survey has revealed that during high productivity years water needs are always met at key points such as plant spiking (this is true both in terms of quantity and in terms of distribution of the precipitation.) In other words, during the period considered and within the observed area, a harvest above the average is the sign of precipitation that, between tilling and spiking, never goes below 40mm and is not concentrated in only one rainfall.

We therefore considered temperature as the *key* parameter for the variation in productivity.

From the foregoing we chose the algorithm CESIA[13]: to provide an estimate of productivity starting from meteo-climatic data:

$$I_p = \frac{1}{G} \sum_{n=1}^{G} \quad \mathrm{mim}_m \, (F_r, F_i, F_t)$$

12. On the year 1740 in the Bologna area see R. Finzi, "Il Sole, la pioggia, ..." 356, 365–6.

13. G. Maracchi, F. Miglietta, "Agrometeorological Models of Agriculture Productivity for Land Planning," in F. Prodi, F. Rossi, G. Cristoferi, eds., *Agrometeorology*, 2nd International Cesena Agriculture Conference (Cesena, 1987), 299ff.

where
F_r radiation factor
F_i water factor
F_t thermal factor
G length of the chosen segment
I_p normalized productivity index

$$\text{becomes } I_p = \frac{1}{G} \sum_{n=S}^{G} [2(tn)^2 - (tn)^4]$$

$$\text{with } tn = \frac{T + (-B)}{T_{max} + (-B)}$$

where T = average temperature calculated in a chosen time segment (day, ten-day period, month,)
−B = minimum growth temperature
Tmax = optimum growth temperature

In this way, during high productivity years, the possible thermal profiles of the agricultural year is mathematically selected and restricted.

The empirical statistical survey on a specimen made in these high productivity years shows that local weather selects an even more limited range of temperature profiles in comparison to the phenological phases of the agricultural years with high productivity (see figs 2–4).

We can, then, conclude that:

(a) Starting from agronomic data we can derive average seasonal data on temperature with a single mode curve characteristic for spring and with a double mode curve characteristic for autumn and winter. We are now engaged in finding a criterion in this latter case to correlate different production/productivity levels with the various temperature profiles previously identified.

(b) With available data on climate besides the agronomic ones, we can reverify the correlation between climate and harvest series independently by the algorithm CESIA. We then have a counter-proof of the reliability of our data.

Our results are still very tentative. Many problems have yet to be solved. We must consider, in particular, the *longue durée,* that is, in this case, long term climate variations. Nevertheless, it is necessary to understand that between the two periods considered, the end of the Little Ice Age actually occurred. Therefore, it is meaningful that our method exhibits coherent results in two different periods that are sharply divided from the point of view of climate history.

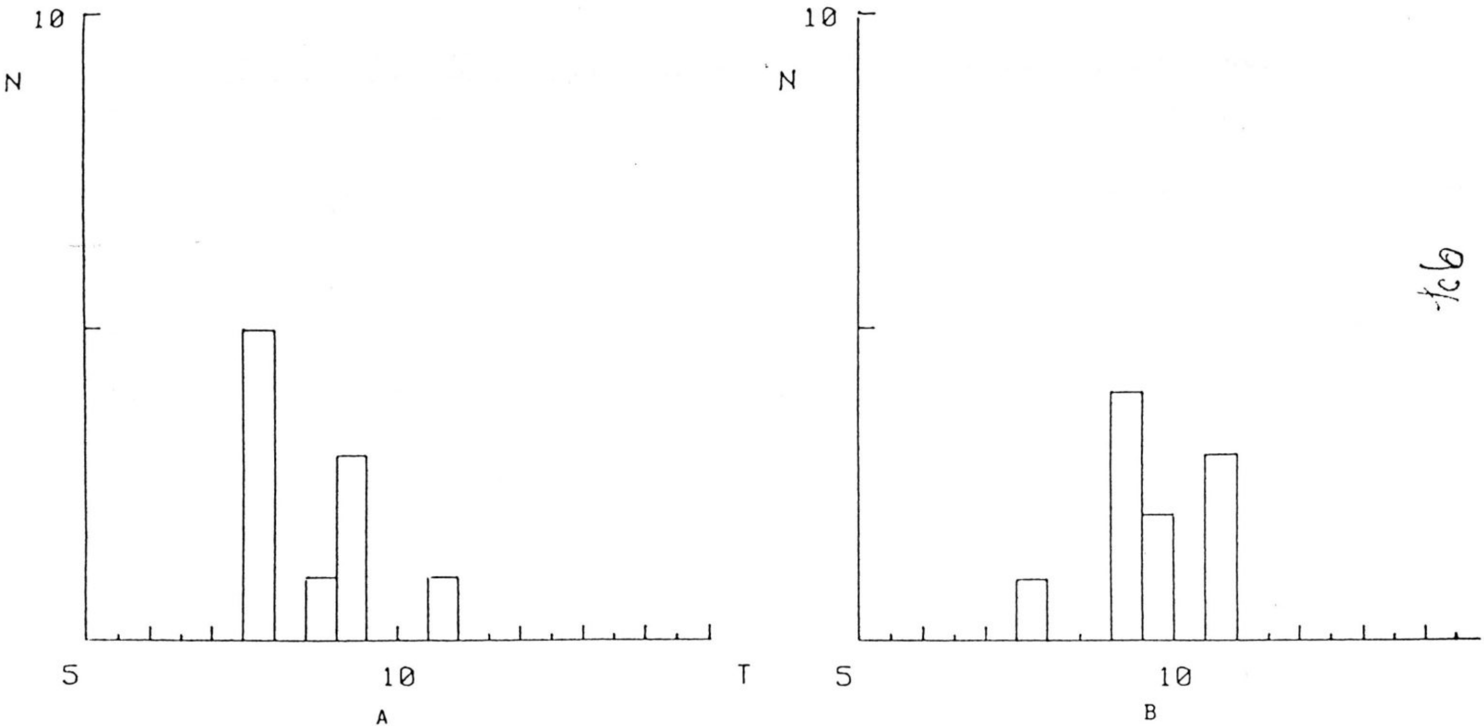

Fig. 2. Frequency (abs. val.) of the Average temperature (°) evaluated on October, November, December for High Production/ Productivity Agricultural years (A = 1815–1860 ; B = 1716–1774).

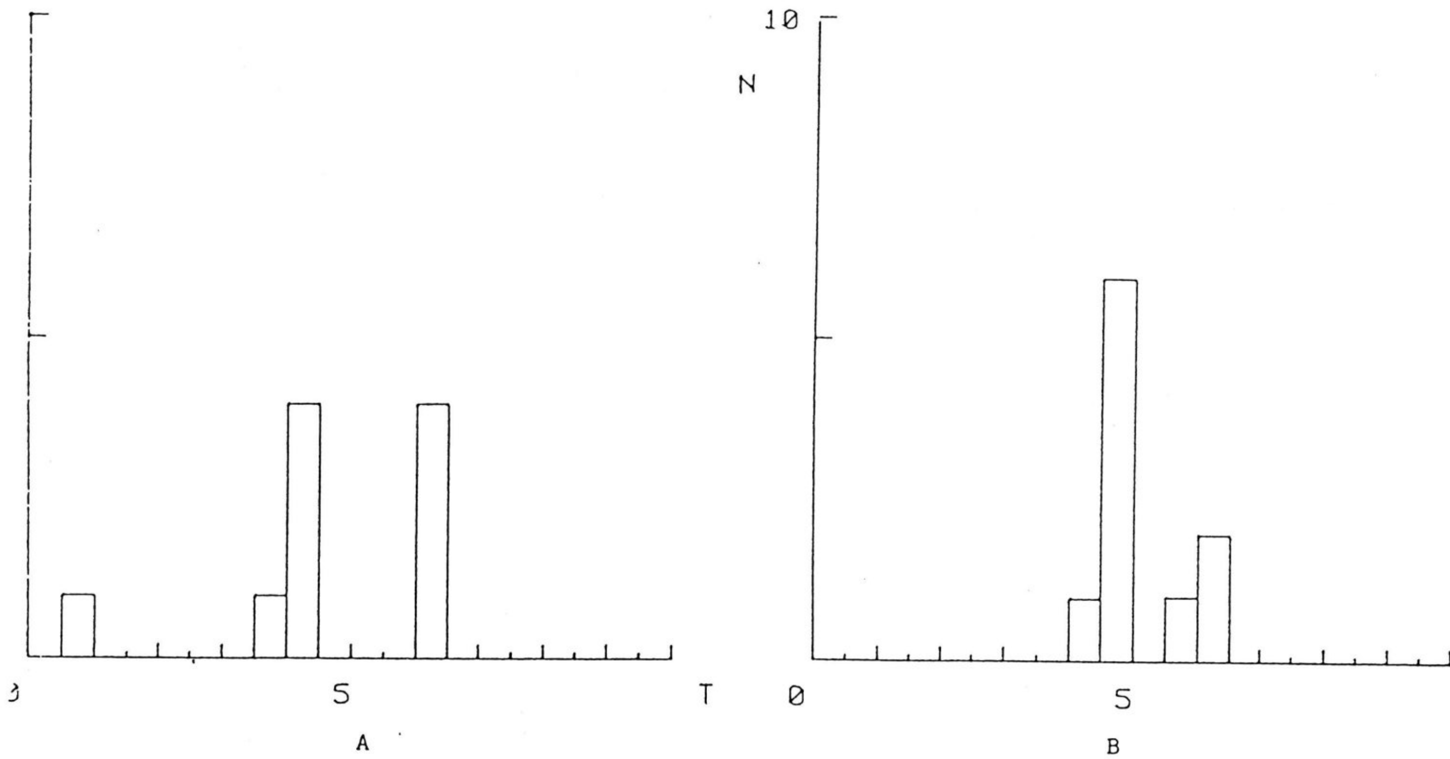

Fig. 3. Frequency (abs. val.) of the Average Temperature (°C) Evaluated on January, February, March for high production/productivity agricultural years (A = 1815–1860 ; B = 1716–1774).

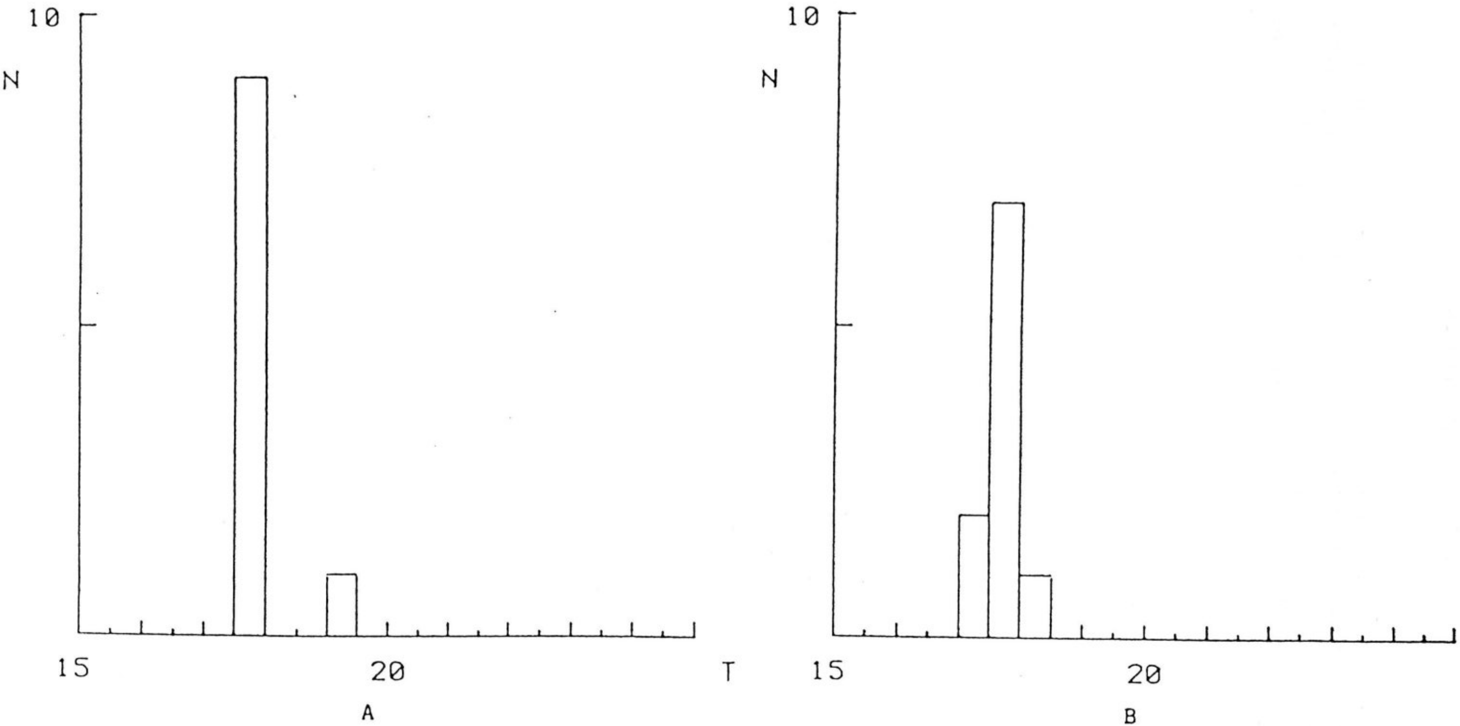

Fig. 4. Frequency (abs; val.) of the Average Temperature (°C) Evaluated on April, May, June for High production/Productivity Years (A = 1815–1860 ; B = 1716–1774).

Precipitation data are notoriously irregular in terms of time and space. At this stage, our method also gives us the possibility of collecting information about the amount of precipitation and the ability to discriminate against concentration in one event only, and eventually to focus on their real distribution.